

A Composite Extreme Ultraviolet QSO Spectrum from FUSE

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Abstract.

The Far Ultraviolet Spectroscopic Explorer (*FUSE*) has surveyed a large sample (> 100) of active galactic nuclei in the low redshift universe ($z < 1$). Its response at short wavelengths makes it possible to measure directly the EUV spectral shape of QSOs and Seyfert 1 galaxies at $z < 0.3$. Using archival *FUSE* spectra, we form a composite extreme ultraviolet (EUV) spectrum of QSOs at $z < 1$ and compare it to UV/optical composite spectra of QSOs at higher redshift, particularly the composite spectrum from archival Hubble Space Telescope spectra.

1. Introduction

The ubiquity with which QSOs display spectral properties such as power-law continua and broad emission lines over wide ranges in luminosity and redshift has led to the use of composite spectra to study their global properties. Infor-

mation about the continuum in the rest-frame ultraviolet is particularly critical for understanding the formation of the emission lines, for characterizing the Big Blue Bump, and for determining the ionization state of the intergalactic medium (IGM). Composite QSO spectra covering the rest-frame ultraviolet have been constructed for objects with $0.33 < z < 3.6$ from *HST* (Zheng et al. 1997, Telfer et al. 2002, T02 hereafter), and at $z > 2$ from ground-based samples like the SDSS (Vanden Berk et al. 2001), the First Bright Quasar Survey (Brotherton et al. 2001) and the Large Bright Quasar Survey (Francis et al. 1991).

The *FUSE* bandpass, 905-1187 Å, allows us to examine the EUV properties of local AGN. We can therefore study the same rest-frame wavelength region covered by the *HST* composite spectra, at redshifts less than 0.33. The low redshifts of these AGN ensure that, although the *FUSE* aperture limits it to observing relatively bright AGN, our sample contains a large fraction of intrinsically low-luminosity objects. An added advantage to working with low redshift spectra is that the determination of the mean EUV spectral index requires a less significant correction for IGM absorption than was required for the *HST* sample.

2. *FUSE* Spectra and Composite Construction

Similarly to T02, we excluded spectra of broad absorption line quasars and spectra with $S/N \lesssim 1$ over large portions from our *FUSE* sample. We also exclude spectra of objects that show strong narrow emission lines, strong stellar features, or strong interstellar molecular hydrogen absorption. A total of 128 spectra of 90 AGN meet the criteria for inclusion in the sample. We follow the same procedure as T02 for the reduction of the sample spectra. To summarize: we correct for Galactic extinction using a standard extinction curve, individual $E(B - V)$ values for each AGN sightline, and $R_V = 3.1$; we ignore wavelength regions affected by ISM absorption lines; we correct for Lyman limit absorption if the S/N below the Lyman break is greater than one; we apply a statistical correction for the line of sight absorption due to the Ly α forest; we shift the AGN spectrum to the rest frame and resample to common 1 Å bins.

The lower redshifts of the *FUSE* AGN compared with the *HST* sample of T02 compels us to use different parameters to perform the correction for Ly α forest absorption mentioned above. Like T02, we describe the distribution of absorbers by $\partial^2 n / \partial z \partial N \propto (1 + z)^\gamma N^{-\beta}$. For the column density distribution parameter, we use the result found by Davé & Tripp (2001) from echelle spectra of two QSOs at $z \sim 0.3$, $\beta = 2.0$ for $12.2 < \log N < 14.4$. For $14.4 < \log N < 16.7$, we use $\beta = 1.35$ from the study by Penton et al. (2000). For the redshift distribution parameter, we use $\gamma = 0.15$ (Weymann et al. 1998). We normalize the distribution of absorbers by $1.34 \times 10^{-11} \text{ cm}^2$ at $\log N = 13$ and $z = 0.17$ and assume a Doppler parameter of 21 km s^{-1} (Davé & Tripp 2001).

We combine the sample spectra using the bootstrap technique described by T02. We begin the bootstrap procedure at the central portion of the output composite. We then include spectra that fall at longer wavelengths in sorted order to longer wavelengths, and spectra at shorter wavelengths in sorted order to shorter wavelengths. The overall composite is renormalized at each step. We fit a power law of the form $F_\nu \propto \nu^\alpha$ to the continuum of the composite spectrum; and find that the best-fit power law index is $\alpha = -0.56$. This is equivalent to

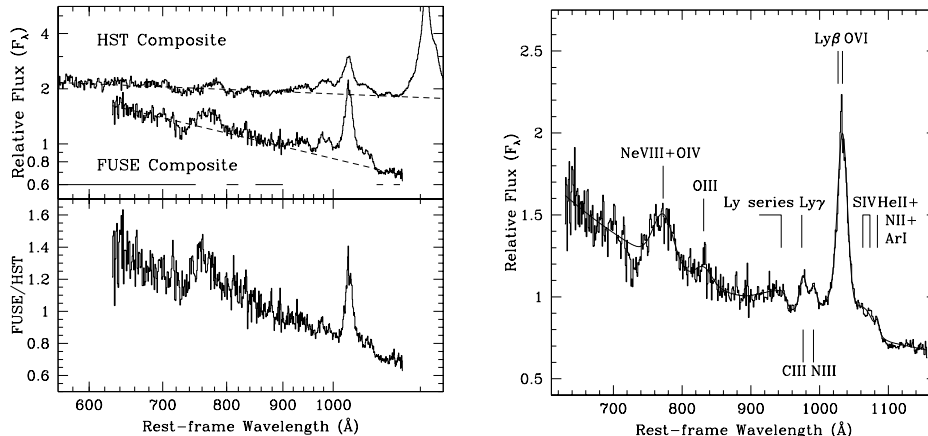


Figure 1. *Top left:* Composite AGN spectrum with power law continuum fit shown by dashed line and wavelength regions used in fit shown by solid line at bottom; *HST* composite from T02 shown for comparison. *Bottom left:* Ratio of *FUSE* to *HST* composite spectra. *Right:* Composite AGN spectrum with emission line fit.

the α_{EUV} fits to wavelengths $> 500 \text{ \AA}$ in T02. We show the composite spectrum and its ratio to the *HST* composite in the left panels of Figure 1. On the right, we show the emission lines fit to the *FUSE* composite.

We find a standard deviation of 0.11 in α from 1000 bootstrap samples of the *FUSE* sample. This gives an estimate of the error arising from the range of spectral shapes of the individual AGN that constitute our sample. We explored a number of possible systematic errors that could affect the spectral shape of the *FUSE* composite spectrum. The results are sensitive to the extinction correction. Changing all individual values of $E(B - V)$ by $\pm 1\sigma$, where we estimate $1\sigma = 0.16E(B - V)$ (Schlegel, Finkbeiner, & Davis 1998) changes α by ± 0.16 . Changing R_V in the extinction law to 4.0(2.8) changes α by $-0.19(+0.06)$. The composite is also sensitive to the value of the column density distribution parameter, β . Reducing it from the chosen fiducial value of 2.0 to 1.7 or 1.5 increases α by up to 0.3. We estimate the total error from the items above, $\alpha = -0.56^{+0.38}_{-0.28}$. The EUV spectral index of the *HST* composite is significantly softer, $\alpha = -1.76 \pm 0.12$. In Figure 2, we show the redshift and luminosity distributions of the *FUSE* and *HST* samples.

3. Summary

We summarize our results as follows:

(1) We construct a composite EUV (630-1155 \AA) AGN spectrum of objects with $z < 0.67$ from archival *FUSE* data. (2) We fit a power law continuum and Gaussian profiles to the emission lines in the composite spectrum, and we find that O VI/Ly β and Ne VIII emission are enhanced in the *FUSE* composite relative to the *HST* composite due to the Baldwin effect, seen also in the comparison between the *HST* and SDSS composites (T02). (3) We find that the best-fit spectral index of the composite is $\alpha = -0.56^{+0.38}_{-0.28}$. The conservative estimate

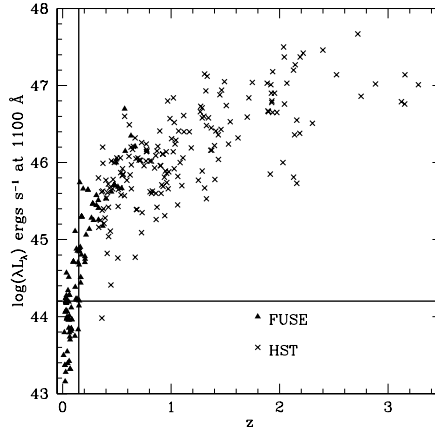


Figure 2. Luminosity versus redshift for *FUSE* and *HST* AGN with lines marking redshift and luminosity cuts.

of the total error in the spectral index includes the standard deviation in α in 1000 bootstrap samples of the *FUSE* data set, uncertainties in the extinction correction applied to the *FUSE* spectra, and uncertainties in the column density distribution parameter of the intervening Ly α forest. (4) The *FUSE* composite is harder than the EUV portion of the *HST* composite spectrum of T02 who find $\alpha = -1.76 \pm 0.12$ for 332 spectra of 184 AGN with $z > 0.33$. The Baldwin effect is generally attributed to the tendency for low-luminosity AGN tend to show harder ionizing continua (Zheng & Malkan 1993; Wang et al. 1998; Dietrich et al. 2002). The median luminosity of the AGN in the *FUSE* sample is $\log L_{\text{median}} = 41.2$, versus $\log L_{\text{median}} = 42.9$ for the *HST* sample. One interpretation of these results is that both the enhanced high-ionization emission line strengths and the harder continuum shape of the *FUSE* composite spectrum are due to the larger fraction of low-luminosity AGN in the *FUSE* sample. However, we note that splitting the *FUSE* sample itself into high- and low-luminosity/redshift subsamples as shown in Figure 2 results in only marginally different values for the EUV spectral index.

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